Dimensional Measurements from Neutron Radiographs

Domanus, J.C.

Publication date:
1989

Document Version
Publisher's PDF, also known as Version of record

Risø-M-2770

RISØ

Riso-M-2770

Dimensional Measurements from Neutron Radiographs

J.C. Domanus

Risø National Laboratory, DK-4000 Roskilde, Denmark
January 1989

RISØ-M-2770

DIMENSIONAL MEASUREMENTS FROM NEUTRON RADIOGRAPHS

J.C. DOMANUS

Abstract. Neutron radiography (NR) can solve many radiographic problems, which cannot be solved neither by X- or gamma-radiography. NR is mainly used for the control of explosives and nuclear fuel elements. In the latter field it is often necessary to determine the dimensions of the object under control from neutron radiographs. There are three main techniques of NR: the direct and transfer technique (using silver halide films and metal converters) and track-etch technique (using nutrocellulose film with coated converters). To check the accuracy of dimensional measurements obtainable with all tehcniques used in NR, a test program was performed by the Euratom Neutron Radiography Working Group (NRWG). For that purpose a calibration fuel pin (CFP), designed and produced at Risø, was used. It contains UO_2 pellets (made of natural and enriched U) enclosed in a zircaloy cladding tube. The UO_2 pellets have different length and are reduced in diameter on half of it. Pellet-to-pellet gaps are formed by Al spacers and pellet-to-cladding gaps by the reduced diameter of half of the pellet. All the CFP dimensions were calibrated during the assembly of the pin. The CFP was thereafter neutron radiographed at 11 NR facilities in 7 NR centers of the 6 countries participating in the NRWG test program. 30 different film/converter combinations were used. From each radiograph 61 different dimensions were measured (25 in the axial and 36 in the radial direction) using a profile projector (projection microscope) and a travelling microdensitometer. Altogether about 25,000 dimensional measurements were made. The accuracy of those measurements was assessed by comparing the measured with the true (calibrated) dimensions and calculating standard deviations. This was done not only for all of the measurements but also separately for different recording techniques, NR facilities and different kinds of dimensions of the CFP. Conclusions were drawn about the accuracies of dimensional measurements which can be expected when using a particular recording technique, NR facilitiy and when measuring a particular kind of dimensions.

January 1989
Risø National Laboratory, DK-4000 Roskilde, Denmark

This paper will be presented at the 12th World Conference on Non-Destructive Testing in Amsterdam, (23-29 April 1989).

ISBN 87-550-1499-2
ISSN 0418-6435

Grafisk Service, Risø, 1989

CONTENTS

1. INTRODUCTION

In neutron radiography (NR) it is often necessary to measure dimensions of the radiographed object from neutron radiographs. High accuracy of dimensional measurements is desired when controlling the behaviour of irradiated nuclear reactor fuel. Here three NR methods are used: the direct, transfer and track-etch technique. The first is used during the pre-irradiation examination of the non-radioactive fuel and the last two for the post-irradiation control of highly radioactive fuel.

To check the accuracy of dimensional measurements obtainable with all the above techniques a test program was set-up by the Euratom Neutron Radiography Working Group (NRWG) in 1981 [1]. This test program was terminated in 1988 and is described in [2 to 8].

Although the dimensional measurements were made from neutron radiographs of a calibration fuel pin (used as a test object) taken on all kinds of recording materials used in NR of nuclear fuel the conclusions drawn from those measurements can also be valid for dimensional measurements taken from X-ray films, exposed to X- or gamma-radiation.

Such films were namely used when testing the fuel pin with the direct and transfer NR methods.

2. MEASURING METHODS AND INSTRUMENTS

The suitability of using various measuring methods and instruments for accurate dimensional measurements from radiographs was previously studied by several authors [9,10,11]. All came to the same conclusion, that for accurate dimensional measurements only two instruments are suitable: the profile projector (projection microscope) (PP) and the travelling microdensitometer (TM). The working principle of both instruments is well known (the principle of measuring images on radiographs was, e.g. described in [12]) and they are both commercially available. Contrary to the profile projector the commercially available travelling microdensitometer did not give satisfactory results as from the micro-

densitometric scan dimensions ought to be determined by inaccurate, subjective methods. This can be avoided when using more sofisticated computer controlled microdensitometers (as e.g. described in [13]).

For the use of measuring dimensions from neutron radiographs a special travelling microdensitometer was designed and built at Geesthacht [14]. It was used throughout the NRWG test program. Some details about the assessment of results reached with this microdensitometer are described in [15]. At Petten a similar travelling microdensitometer was built and is described in [16].

3. CALIBRATION FUEL PIN

For the purpose of checking accuracy of dimensional measurements from neutron radiographs a special calibration fuel pin (CFP) was designed and produced at Risø for all participants of the NRWG Test Program. It is shown in fig. 1 and was described in [17] (as well as in [1,2,6,8]). Its design incorporates the following features:

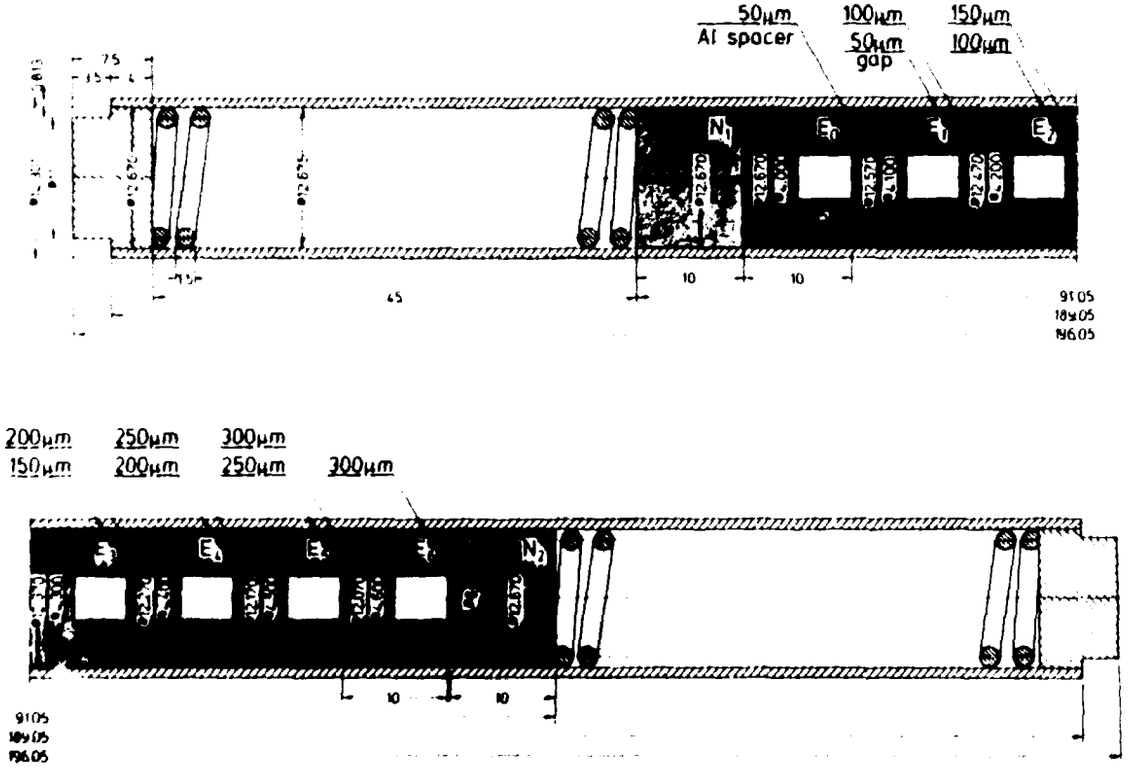

Fig. 1. Calibration fuel pin CFP-E1

- From the 9 UO_2 pellets two are made of natural, and seven of enriched uranium.
- All the pellets have different lengths.
- Each of the two pellets made of natural uranium and one of enriched uranium has a constant diameter throughout its length, to fit closely into the zircaloy cladding tube (there are practically no fuel-to-cladding gaps).
- Each of the remaining six UO_2 pellets of enriched uranium has a reduced diameter on half of its length so as to form a calibrated fuel-to-cladding gap. These radial gaps are 50, 100, 150, 200, 250, and 300 μm wide.
- The first UO_2 pellet from natural uranium and the first of enriched uranium have a dishing 0.3 mm deep on the surfaces facing each other.
- There are aluminium spacers between all UO_2 pellets from enriched uranium. They are simulating the pellet-to-pellet gaps. The thicknesses of those spacers are the same as the fuel-to-clad gaps, i.e. 50, 100, 150, 200, 250, and 300 μm.
- All UO_2 pellets made of enriched uranium have a calibrated central void. The diameter of this void is 4.00 mm and increases by an increment of 0.10 mm throughout the consecutive pellets to a diameter of 4.60 mm.

From each radiograph of the CFP-E1 61 different dimensions (25 in the axial and 36 in the radial direction) were measured, using a profile projector and a travelling microdensitometer.

Altogether about 25,000 dimensional measurements were made. The accuracy of those measurements was assessed by comparing the measured with the true (calibrated) dimensions and calculating standard deviations. This was done not only for all of the measurements but also separately for different recording techniques, NR facilities and different kinds of dimensions of the CFP.

4. DETECTION SYSTEMS AND EXPOSURE TECHNIQUES

During the investigation two detection systems were used. One (used for the direct and transfer method) consists of a metal

conversion screen and a silver halide film; the other (used for the track-etch method) of a nitrocellulose film coated on both sides with a conversion screen or a nitrocellulose film and two separate conversion screens. Metal conversion screens and silver halide films were used with both the direct as well as the transfer method.

With the track-etch method nitrocellulose film was used with conversion screens. Those conversion screens were either used as a coating on the nitrocellulose film or as separate screens.

The CFP with other test items was simultaneously radiographed on a 9 x 12 cm film using 30 different film/converter combinations as shown on Fig. 2. One set of films was processed at NR centers (left side of Fig. 2) and a separate set of identically exposed films was sent to Risø for processing (right side of Fig. 2).

	Processed at																	
	NR center								RISØ									
Converter	Gd			Dy			B	BN1	Gd			Dy			B		BN1	
Film	SR	D4	M	SR	D4	M	CNB	CN	SR	D4	M	SR	D4	M	CNB		CN	
Code No	1	3	5	7	9	11	13	22	2	4	6	8	10	12				
Etched at															20°C	50°C	20°C	50°C
Code No															16	19	25	28
Copy on							S0015								S0015			
Code No							14	23							17	20	26	29
Viewed through	Polarizing filters																	
Code No							15	24							18	21	27	30

Fig. 2. NRWG Test Program

All the three techniques were used. With the direct technique Kodak SR and M, and Agfa Gevaert D4 films were exposed with a 25 μm Gd converter. The same three films with a 100 μm Dy converter were used in the transfer technique. For the track-etch technique a nitrocellulose Kodak-Pathé CN85 type B film was used (double-coated with converter) and the CN85 nitrocellulose film sandwiched between two BN1 converters. The nitrocellulose films pro-

cessed at Risø were etched at 20°C for 21 h and at 50°C for 45 min. All the nitrocellulose radiographs were also copied on a high contrast duplicating film (Kodak S0015 or 4168). They were also viewed through polarizing filters.

5. DIMENSIONAL MEASUREMENTS

The dimensions of the CFP were measured at each NR centre using a conventional profile projector. Besides 69 radiographs were separately measured on a travelling microdensitometer, designed at Geesthacht and on a Joyce Loebl travelling microdensitometer at Saclay. Altogether 273 neutron radiographs were measured on the profile projector and 129 on a travelling microdensitometers (402 in all).

From neutron radiographs of the CFP-E1 axial and radial measurements were made separately. The axial measurements of fuel stack length, pellets length, pellet-to-pellet gaps, dishing in pellet and central void length comprised 25 measurements from each radiograph.

The radial measurements of pellet diameter, cladding tube wall thickness, pellet-to-clad gaps and central void diameter comprised 36 measurements. So altogether 61 separate measurements were taken from each radiograph.

For the whole Test Program altogether 13,908 measurements were made at NR centres and 10,614 at Risø (total of 24,522 measurements). From those measurements absolute (in μm) and relative (in %) deviations were calculated as a difference between the measured and true dimensions. Those three values (measured, absolute and relative deviation) were listed for all 11 NR facilities and 30 film/converter combinations.

6. ACCURACY OF DIMENSIONAL MEASUREMENTS

The accuracies of dimensional measurements were assessed by calculating standard deviations for differences between the measured and true values of particular dimensions of the CFP.

Measuring results were grouped in different ways so as to allow to compare standard deviations calculated for those groups, which represent different measuring techniques and instruments, recording materials and viewing techniques.

Additionally, two sets of neutron radiographs were measured on two types of travelling microdensitometers.

Altogether 24, 522 dimensional measurements were made as shown in table 1.

Table 1. Total number of measurements

Dimensions	Profile projector			Travelling microdensitometer			Total		
	Risø	Others	Total	Risø	Others	Total	Risø	Others	Total
Axial	4350	2478	6825	-	3225	3225	4350	5700	10050
Radial	6264	3564	9828	-	4644	4644	6264	8202	14472
Total	10614	6039	16653	-	7869	7869	10614	13908	24522

From neutron radiographs of a calibration fuel pin different dimensions are measured both in the axial as well as in the radial direction.

When measuring the axial dimensions of the pin one masures essentially distances between sharp edges depicted on the radiographs.

The measurement of radial dimensions of the pin consists essentially of measuring distances of projections of round objects. As is well known it is much more difficult to measure the distances of round objects than of sharp edges. Therefore, accuracy of dimensional measurements was analyzed separately for axial and radial dimensions.

7. MEASURING RESULTS

The calculations of standard deviations were done separately for different exposure and viewing techniques, processing modes and different NR facilities.

First the calculation was done with taking into account all the measurements performed at all NR facilities participating in the Test Program. Thus a general idea of accuracies, which can be reached by measuring dimensions from neutron radiographs taken at any NR facility could be obtained. Thereafter the calculations were split into groups taking into account such factors as the measuring techniques and instruments.

As a principle axial and radial measurements of the dimensions of the calibration fuel pin were done in different geometric conditions, due to different projections of fuel pin elements in the axial and radial direction. Therefore one could expect different measuring accuracies in both cases.

Therefore calculations were always made separately for axial and radial measurements.

After calculating standar deviations for all dimensional measurements, they were split separately for those done with the profile projectors (PP) and travelling microdensitometers (TM). (Geesthacht microdensitometer - MG and Saclay microdensitometer - MS). On Fig. 3 general comparison of results is given.

The calibration fuel pin CFP-E1 was neutron radiographed using three different exposure techniques: the direct, transfer and track-etch method.

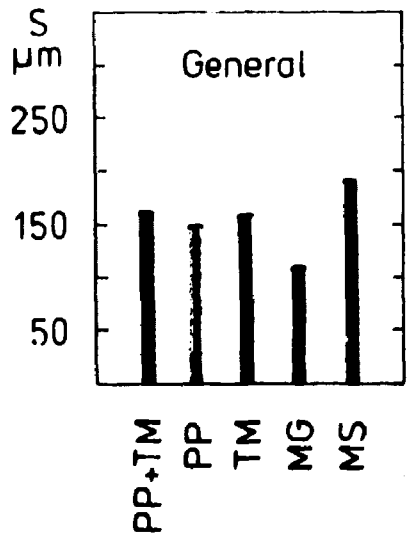

Fig. 3. General comparison of results

To be able to say which of the three exposure methods gives best accuracies in dimensional measurements standard deviations were calculated for all neutron radiographs exposed by those techniques. The results are given in Fig. 4, where also results reached for neutron radiographs exposed on silver halide film (direct + transfer technique) are shown.

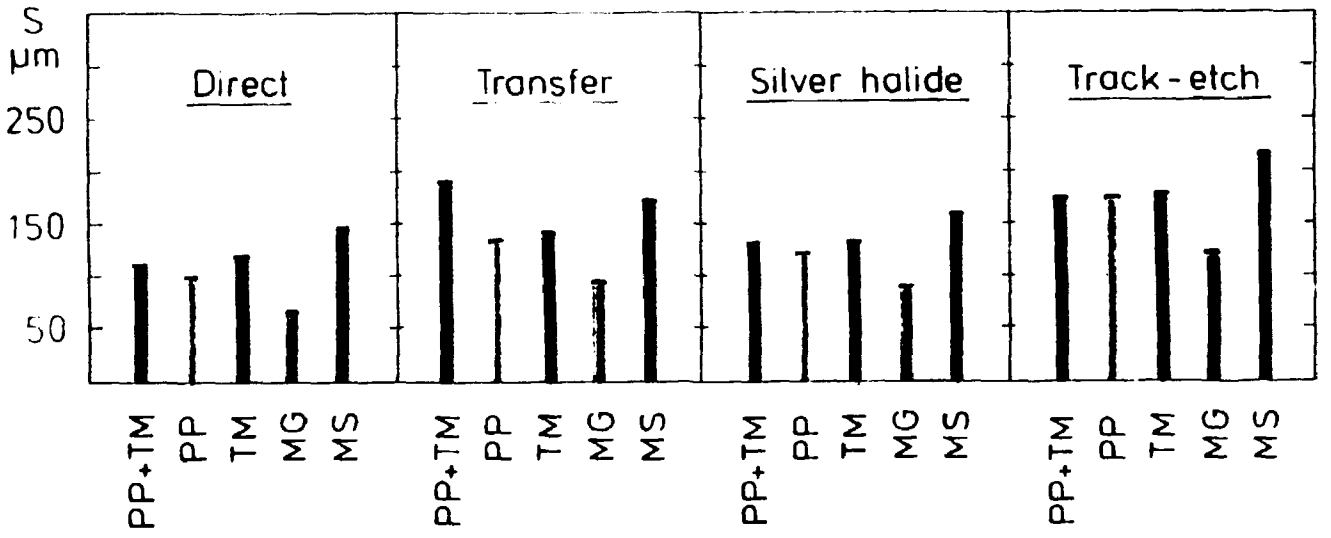

Fig. 4. Different exposure techniques

Nitrocellulose films can be viewed by three methods: directly (as silver halide films), from copies on high contrast duplicating film (also as the silver halide films) or through prolarizing filters. To be able to assess the relative merits of those three methods an analysis was made of the measuring results (see Fig. 5).

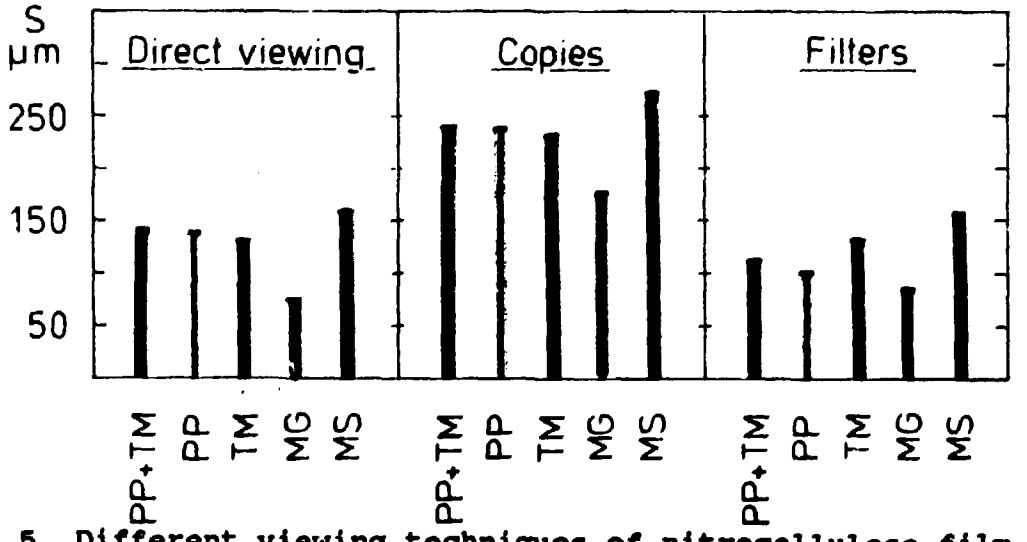

Fig. 5. Different viewing techniques of nitrocellulose film

8. CONCLUSIONS

1) For dimensional measurements of the CFP always better results were reached for radial (R) than for axial (A) measurements. This was due to the dimensional distortion of axial dimensions on the radiographs. Only those parts of the calibration fuel pin which were positioned in the middle of the neutron beam had undistorted sharp edges on the neutron radiographs.

2) When speaking about measuring accuracies one must remember that they depend greatly on the different kinds of dimensions to be measured from a fuel pin. If all kinds of dimensions are taken into account together one must expect the worst measuring accuracy. If, however, one is interested to measure only one particular group of dimensions then the measuring accuracies will be much better. Therefore when specifying a certain measuring accuracy one must always specify also the group of dimensions (e.g. tube wall, gaps, pellet diameters) to which this accuracy pertains.

3) The measuring accuracies may be different for different film/ converter combinations. This was investigated in detail during the NRWG Test Program

4) For nitrocellulose film the viewing technique is of importance. The investigation has shown that the measuring accuracies reached when measuring dimensions from copies of the nitrocellulose film on high contrast silver halide film are inferior to those for the nitrocellulose film viewed directly or through polarizing filters. However, this last method is not suitable for use with the travelling microdensitometer.

5) The measuring accuracies depend also on the measuring instrument in use. Measurements performed by the use of a profile projector (PP) are subjective measurements. When compared with the mean results reached for two types of travelling microdensitometers (TM) used throughout the in-

vestigation they show almost the same measuring accuracies. However, if only the results of a special travelling microdensitometer designed and constructed at Geestacht (MG) are taken into account then the results for the (MG) are much better than for the (PP). In comparing the microdensitometric with the profile projector method one must remember that microdensitometric measurements are much more time consuming.

6) The last factor that must be mentioned in connection with evaluating the influence of different factors on the measuring accuracies is the human factor. As the investigation has shown even if the same measurements are made from the same film using the same type of measuring instrument the results may be different.

7) To find the proper answer to the question about the measuring accuracy to be expected in a particular case one must take into account all the factors mentioned above. Details about them can be found in the full report about the NRWG Test Program [2,3,4,5,8].

REFERENCES

[1] J.C. Domanus. Revised test program for testing of the CFP-E1; ASTM (revised) BPI and SI and BPI-F. Risø Report B-512. August 1981.

[2] J.C. Domanus. Assessment of the NRWG Test Program. Part I. Test items, exposure and recording techniques, measurements. Risø National Laboratory, Metallurgy Department, August 1987.

[3] J.C. Domanus. Assessment of the NRWG Test Program. Part II. Assessment of the use of BPI, BPI-F and SI. Risø National Laboratory, Metallurgy Deparmtnet. January 1988.

[4] J.C. Domanus. Assessment of the NRWG Test Program. Part III. Assessment of dimensional measurements. Risø National Laboratory, Metallurgy Department. February 1988.

[5] J.C. Domanus. Assessment of the NRWG Test Program. Part IV.

Conclusions Risø National Laboratory, Metallurgy Department. April 1988.

[6] J.C. Domanus. International Neutron Radiography Newsletter No 15 - NRWG Test Program. Part 1. British Journal of NDT. January 1988, 40-42.

[7] J.C. Domanus. International Neutron Radiography Newsletter No 17 - NRWG Test Program. Parts 2, 3 & 4. British Journal of NDT (in press).

[8] J.C. Domanus. Neutron Radiography Working Group Test Program. November 1988. To be published as an EUR report.

[9] R.S. Matfield, G. Constantine and S.C. Alexander. The measurement of small dimensional changes by neutron radiography. AERE-R 5792 (1969).

[10] T. Robertson. Neutron radiography in the precision measurement of irradiated material. In Radiography with Neutrons. British Nuclear Energy Society, London, 1975, 107-111.

[11] J.C. Domanus. Accuracy of dimension measurements from neutron radiographs of nuclear fuel pins. Risø-M-1860. 26.03.1976 and Eight World Conference on Nondestructive Testing. Cannes, 6-11.09.1976. Paper 3L-8.

[12] G.M. Taylor. Photodensitometer measurements of images on radiographs. UCRL-52037, 12.03.1976.

[13] J.S. Spunda. First experience in using microdensitometer "Scanding 3" - Joyce Loebl for autoradiography evaluation. Isotopenproxis [14], 7/1978. 209-211.

[14] L. Greim, M. Greim, H.-W. Schmitz, G.W. Schumacher. Computer controlled microdensitometer and some applications. 669-677 in Proceedings of the Second World Conference on Neutron Radiography.

[15] M. Wrobel, L. Greim. Resolution functions and unsharpness in neutron radiography. GKSS88/E/12. 9.2.1988.

[16] K. van Otterdijk, B. Shapiro, H.P. Leeflang, J.F.W. Markgraf. Computer controlled travelling microdensitometer. 687-692 in Proceedings of the Second World Conference on Neutron Radiography.

[17] J.C. Domanus. Calibration fuel pin CFP-E1. Risø National Laboratory, Metallurgy Department. B-511. August 1981.

Risø National Laboratory **Risø - M - 2770**

Title and author(s)	Date January 1989
DIMENSIONAL MEASUREMENTS FROM NEUTRON RADIOGRAPHS J.C. Domanus	Department or group Metallurgy
	Groups own registration number(s)
	Project/contract no.
Pages 17 Tables 1 Illustrations 5 References 17	ISBN 87-550-1499-2

Abstract (Max. 2000 char.)

Neutron radiography (NR) is mainly used for the control of explosives and nuclear fuel elements. It is often necessary to determine the dimensions of the object under control from neutron radiographs. To check the accuracy of dimensional measurements obtainable with all tehcniques used in NR, a test program was performed by the Euratom Neutron Radiography Working Group (NRWG). For that purpose a calibration fuel pin (CFP), designed and produced at Risø, was used. The CFP was thereafter neutron radiographed at 11 NR facilities in 7 NR centers of the 6 countries participating in the NRWG test program. 30 different film/converter combinations were used. 61 different dimensions were measured, using a profile projector and a travelling microdensitometer. Altogether about 25,000 dimensional measurements were made. The accuracy of those measurements was assessed by comparing the measured with the calibrated dimensions and calculating standard deviations.

Descriptors - INIS

ACCURACY; CALIBRATION; DIMENSIONS; FUEL PINS; NEUTRON RADIOGRAPHY

Available on request from Risø Library, Risø National Laboratory, (Risø Bibliotek, Forskningscenter Risø), P.O. Box 49, DK-4000 Roskilde, Denmark.
Telephone 02 37 12 12, ext. 2262. Telex: 43116, Telefax: 02 36 06 09

Available on exchange from:
Risø Library,
Risø National Laboratory,
P.O. Box 49, DK-4000 Roskilde, Denmark
Phone 42 37 12 12, ext. 2268/2269,
Telex 43116, Telefax 46 75 56 27

ISBN 87-550-1499-2
ISSN 0418-6435